



Phase 2 of the Energy Storage Proceeding

Possible Models to Assess Cost Effectiveness

September 24, 2012



DNV - Integrity at the core



- Independent foundation established in 1864
- Self-owned with no shareholders
- Stakeholders are represented in our governing bodies and committees
- We use profits to continuously develop our people and our research and innovation

DNV KEMA - Energy & Sustainability

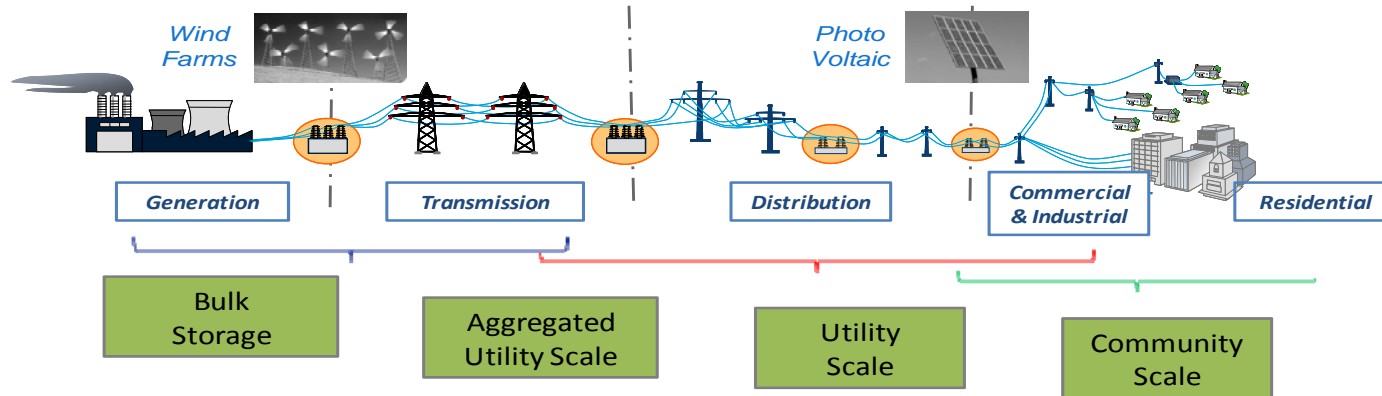


- DNV KEMA Energy & Sustainability offers innovative solutions to customers across the energy value chain, ensuring reliable, efficient and sustainable energy supply, now and in the future.
- 2300+ experts across all continents
- KEMA and DNV combined: a heritage of nearly 150 years
- US Headquarters in Burlington, MA
- Offices and agents in over 30 countries around the globe
- DNV Global: 300 Offices, 100 Countries, 10,400 Employees

Contents

1	Examples of DNV KEMA Tools
2	Review of ES-Select
3	Review of Distribution Valuation Model
4	Review of DNV KERMIT Model
5	Example of Applying to Use Case

DNV KEMA Analysis Tools for Storage



- KEMA Tools are targeted to assess storage at each area of the grid
 - **ES Select:** Targeted to weigh various technologies of storage against specific applications and incorporating “bundling features” into the analysis – used at all levels of the grid
 - **Distribution Valuation Tool:** Designed to assess benefits of storage applications at the distribution level through simulated circuit analysis – focused on distribution
 - **KERMT Model:** Real time Simulation model to assess storage at the whole sale, generation level – focuses on renewable integration and regulation
 - **Peaker Model:** Tool to assess storage as a peaker substitute
- Slides focus on ES-Select, Distribution Valuation Tool, and KERMIT Model

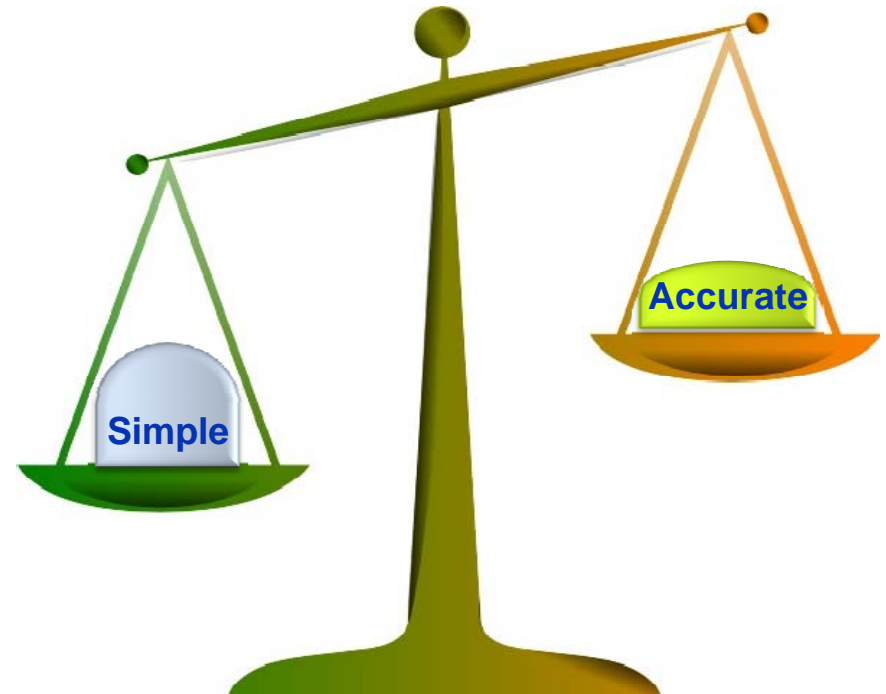
Contents

- | | |
|---|--|
| 1 | Examples of DNV KEMA Tools |
| 2 | Review of ES-Select |
| 3 | Review of Distribution Valuation Model |
| 4 | Review of DNV KERMIT Model |
| 5 | Example of Applying to Use Case |

What Does ES-Select Provide?

Why Build This Model?

- Prioritized list of **feasible energy storage technology options** for targeted applications
- **Cost-performance comparison** of feasible storage technologies
- **10-year technical market potential** of applications in North America
- **Present Value benefits over 10-years** for applications in North America



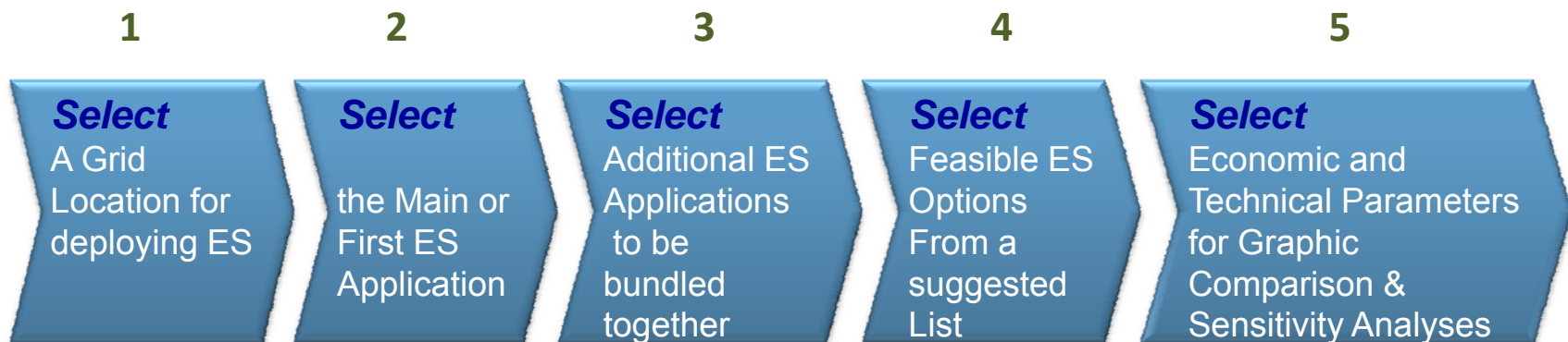
Where to Find the Public Version of This Model?

<http://www.sandia.gov/ess/esselect.html>

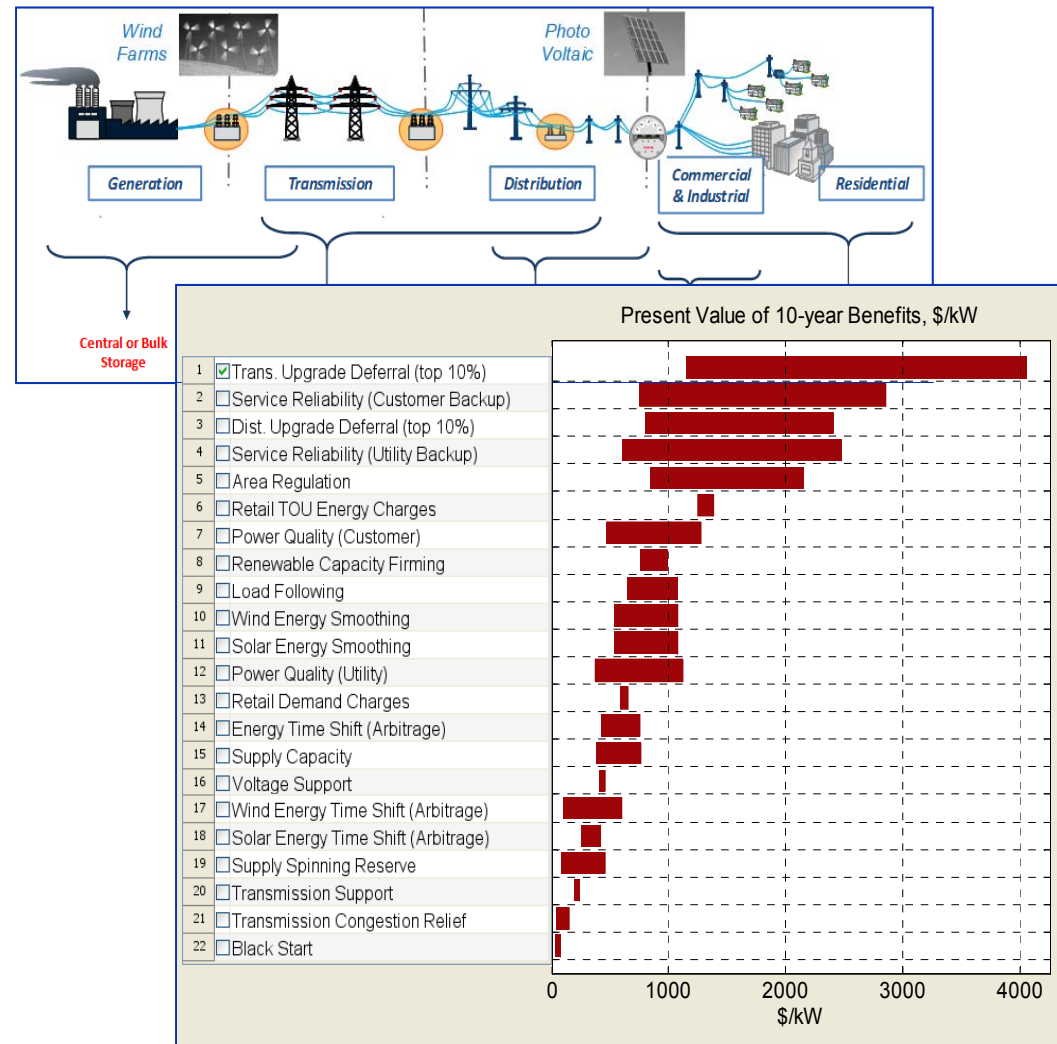
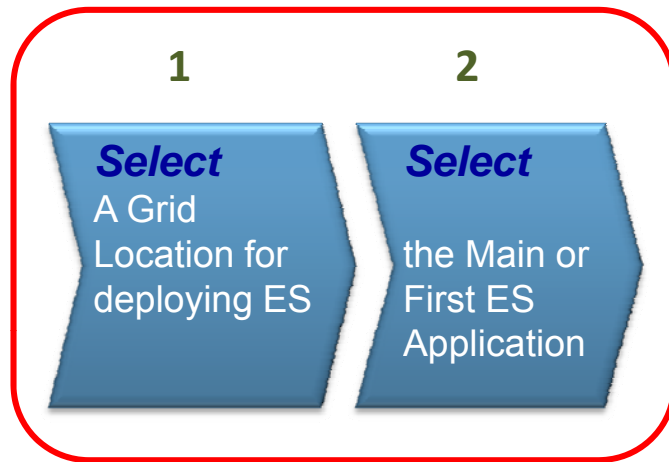
ES-Select Overview

In a step-by-step interactive manner, ES-Select identifies and compares the feasible Energy Storage (ES) options for different grid applications

1. Asks: Location
2. Asks: Main Application
3. Option for: Additional Applications
4. Offers: Feasible ES Options
5. Compares the feasible ES Options



First Two Steps – Where & What Application?



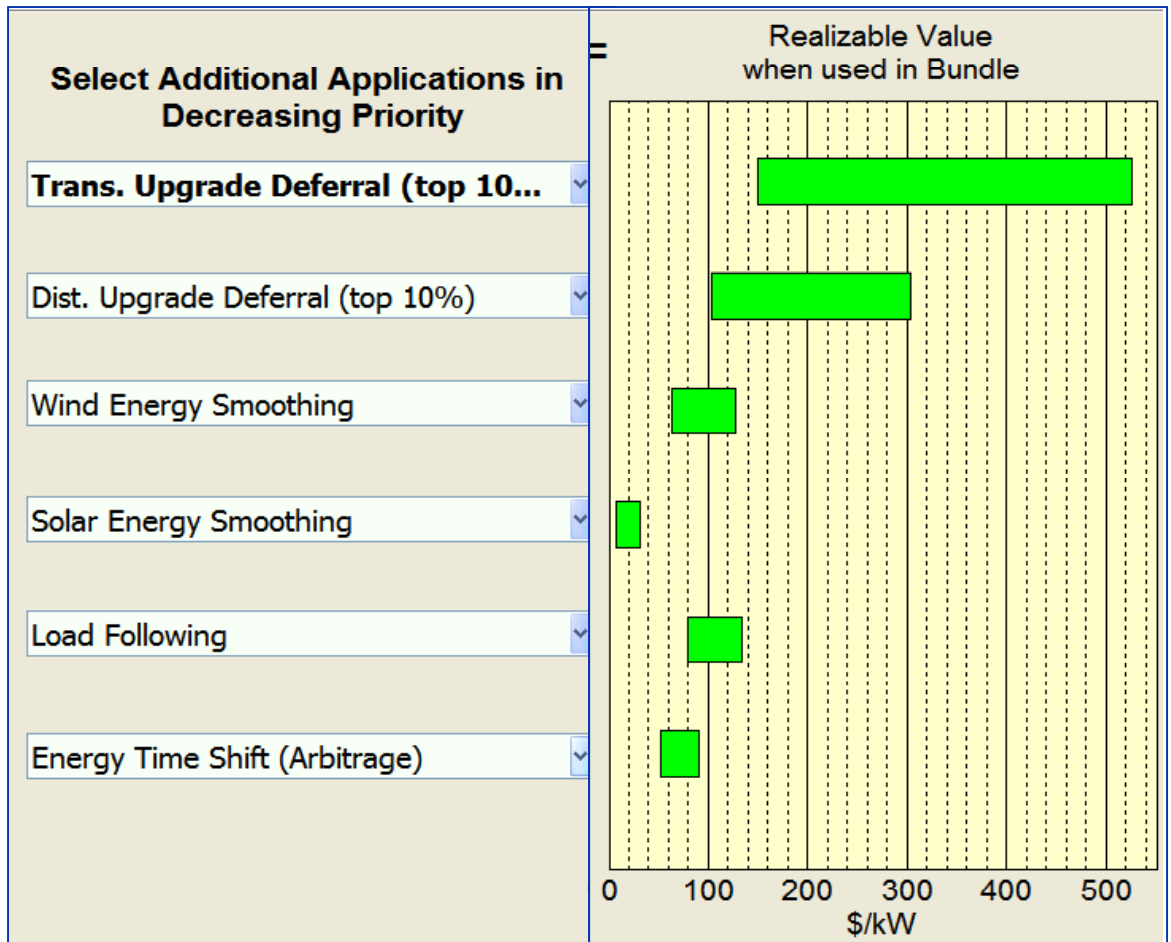
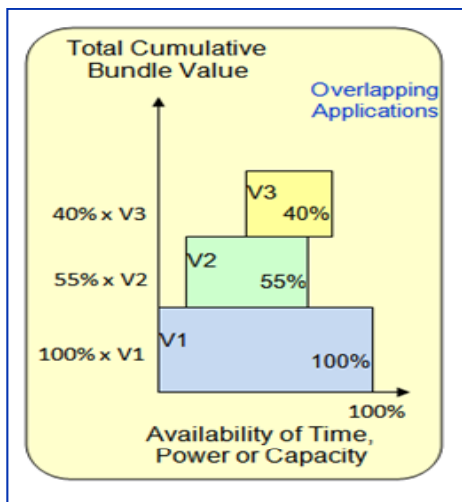
Next - Selection of Additional Applications

ES-Select identifies the next highest-value application, if desired.

3

Select

Additional ES Applications to be bundled together



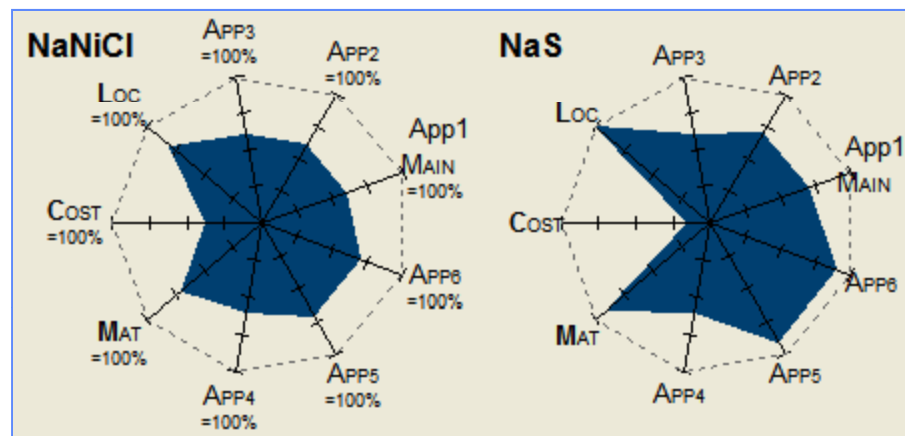
Output – A List of Feasible Storage Options

ES-Select Sorts Suggested ES options by their “feasibility Score”

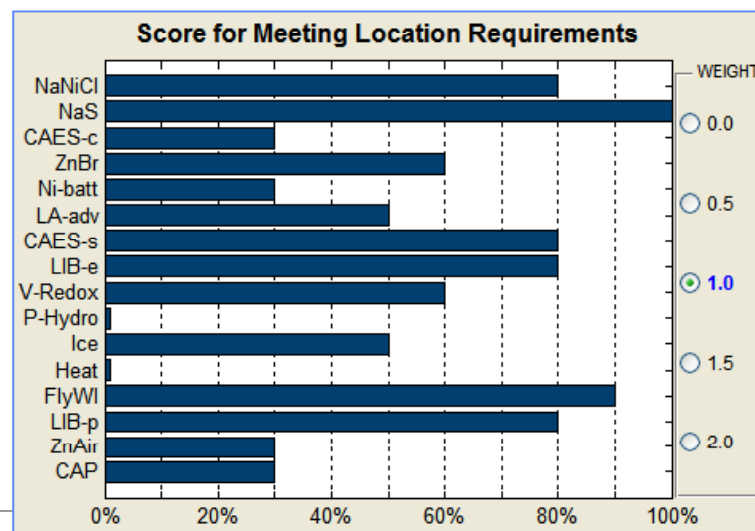
4

Select

Feasible ES
Options
From a
suggested
List



1	<input checked="" type="checkbox"/>	Sodium Nickel Chloride	NaNiCl	60%
2	<input checked="" type="checkbox"/>	Sodium Sulfur	NaS	56%
3	<input checked="" type="checkbox"/>	Compressed-Air ES, cavern	CAES-c	54%
4	<input checked="" type="checkbox"/>	Zinc Bromide	ZnBr	54%
5	<input checked="" type="checkbox"/>	Ni batt. (NiCd, NiZn, NiMH)	Ni-batt	51%
6	<input checked="" type="checkbox"/>	Advanced Lead Acid	LA-adv	51%
7	<input type="checkbox"/>	Compressed-Air ES, small	CAES-s	46%
8	<input type="checkbox"/>	Lithium Ion - High Energy	LIB-e	42%
9	<input type="checkbox"/>	Vanadium Redox Battery	V-Redox	31%

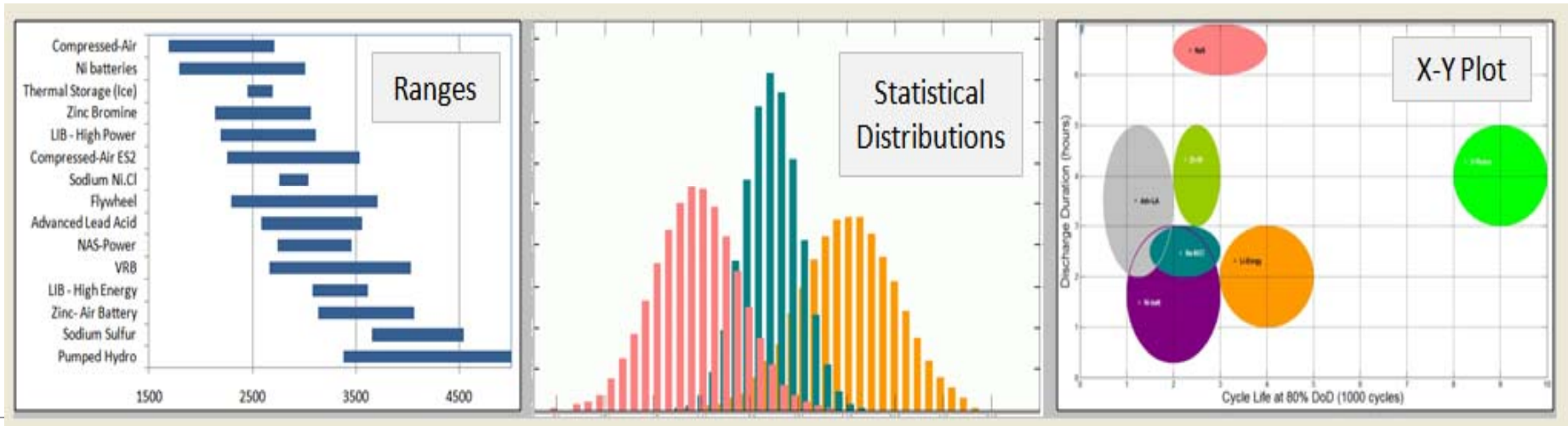


Last- Apples-to-Apples Comparison of Options

5

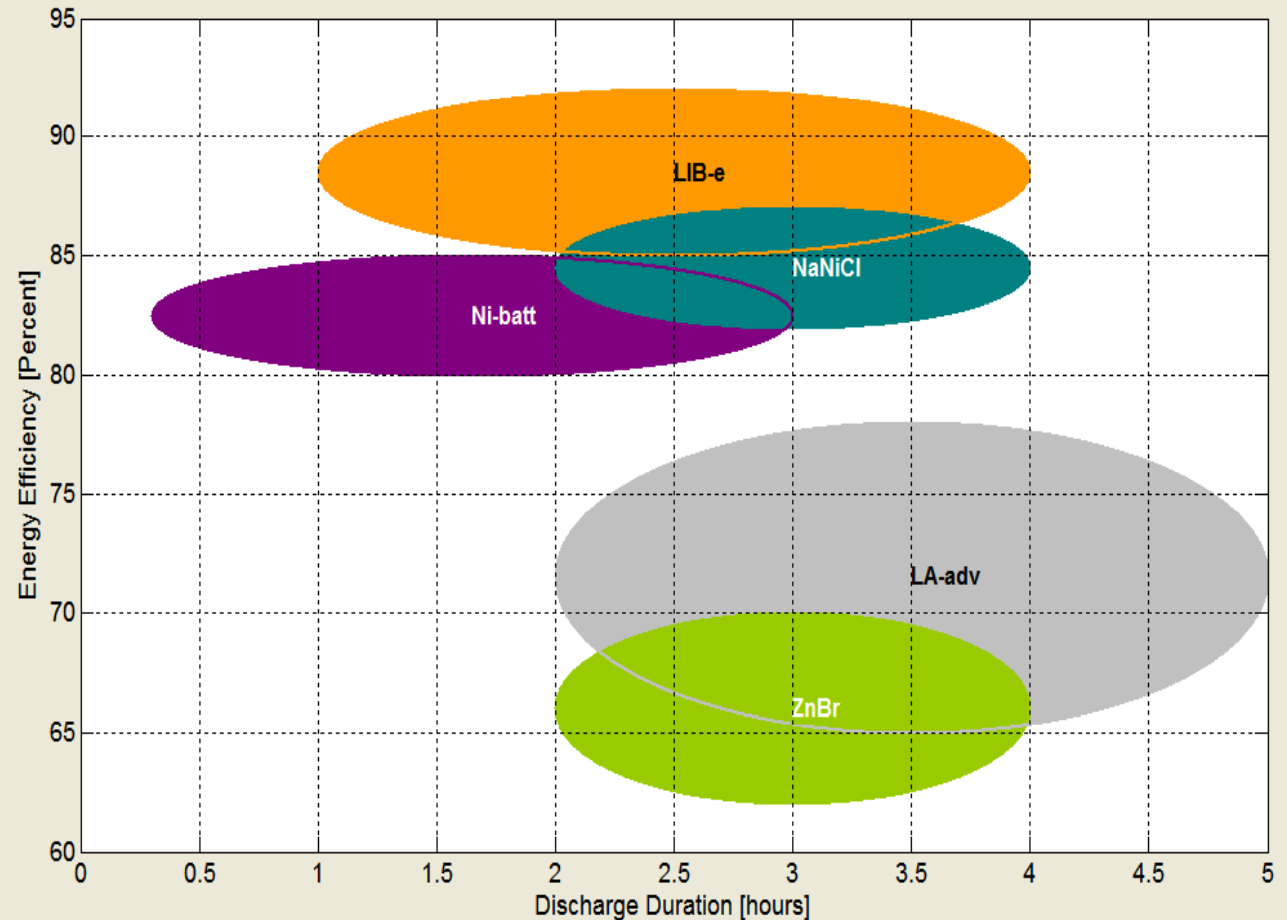
Select

Economic and
Technical Parameters
for Graphic Comparison
& Sensitivity Analyses



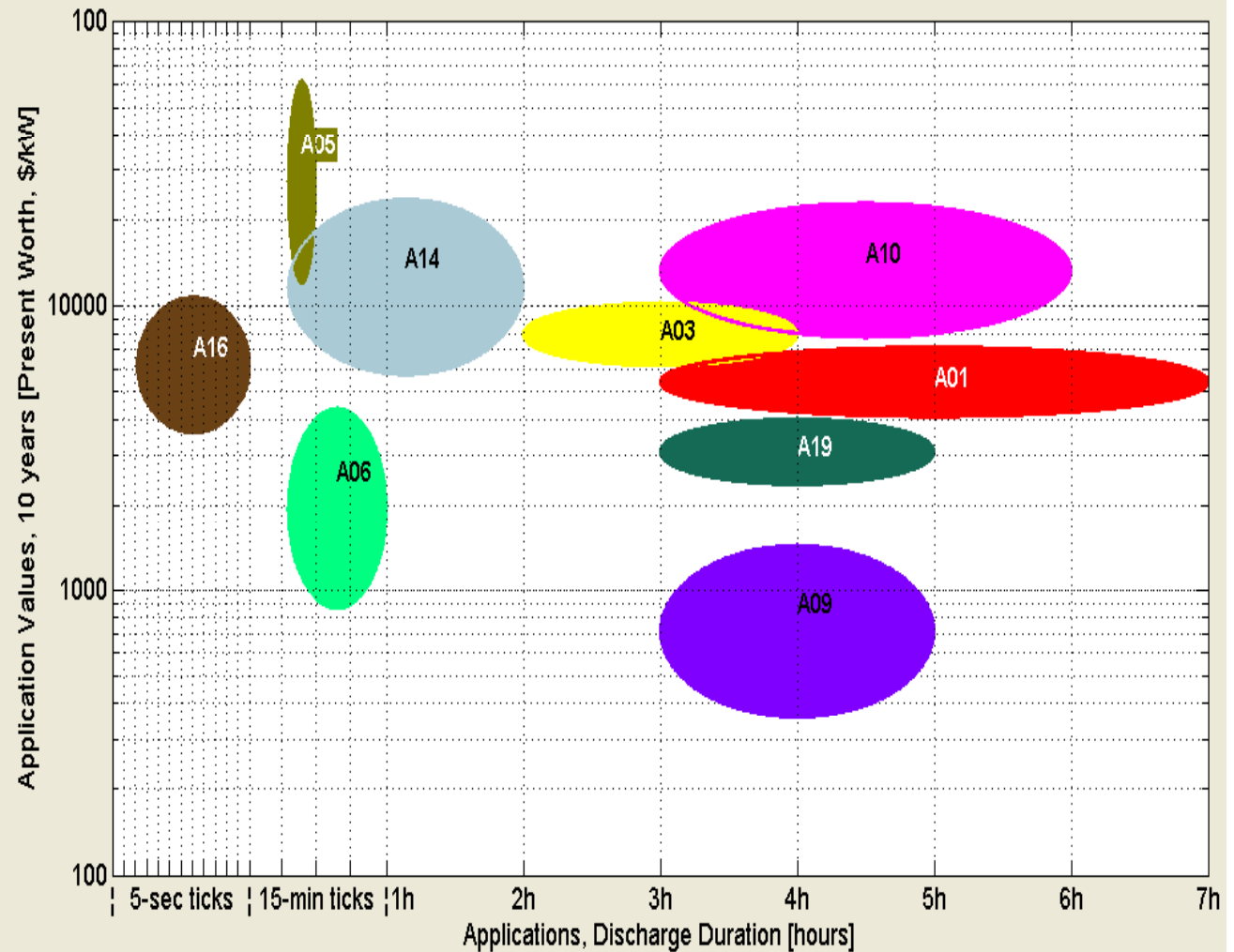
Sample Outputs – Bubble Charts

1	<input checked="" type="checkbox"/> Sodium Nickel Chloride	NaNiCl	63%
2	<input checked="" type="checkbox"/> Advanced Lead Acid	LA-adv	55%
3	<input checked="" type="checkbox"/> Ni batt. (NiCd, NiZn, NiMH)	Ni-batt	53%
4	<input checked="" type="checkbox"/> Lithium Ion - High Energy	LIB-e	50%
5	<input checked="" type="checkbox"/> Zinc Bromide	ZnBr	49%
6	<input type="checkbox"/> Compressed-Air ES, small	CAES-s	36%
7	<input type="checkbox"/> Sodium Sulfur	NaS	34%
8	<input type="checkbox"/> Zinc- Air Battery	ZnAir	32%
9	<input type="checkbox"/> Vanadium Redox Battery	V-Redox	27%
10	<input checked="" type="checkbox"/> Compressed-Air ES, cavern	CAES-c	0%
11	<input checked="" type="checkbox"/> Pumped Hydro	P-Hydro	0%
12	<input checked="" type="checkbox"/> Thermal Storage (Cold)	Ice	0%
13	<input checked="" type="checkbox"/> Thermal Storage (Hot)	Heat	0%
14	<input checked="" type="checkbox"/> Lithium-ion - High Power	LIB-p	0%
15	<input checked="" type="checkbox"/> Flywheel	FlyWI	0%
16	<input checked="" type="checkbox"/> Ultra/Super Capacitors	CAP	0%



Sample Outputs – Special Charts

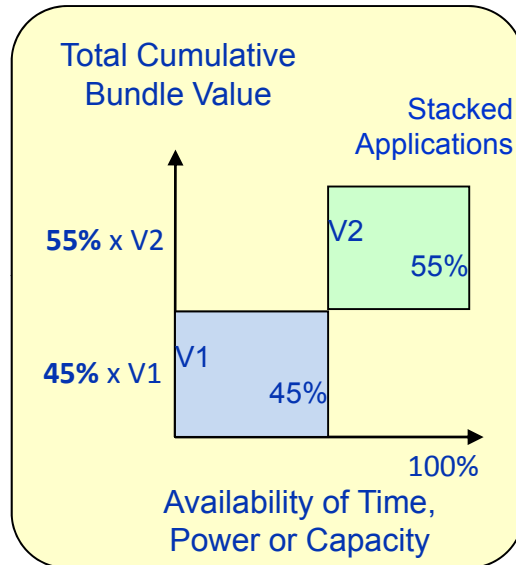
<input checked="" type="checkbox"/> Dist. Upgrade Deferral (top 10%)	A10
<input checked="" type="checkbox"/> Fast Regulation	A05
<input type="checkbox"/> Trans. Upgrade Deferral (top 10%)	A11
<input checked="" type="checkbox"/> Load Following	A03
<input checked="" type="checkbox"/> Energy Time Shift (Arbitrage)	A01
<input type="checkbox"/> Supply Capacity	A02
<input type="checkbox"/> Area Regulation	A04
<input checked="" type="checkbox"/> Supply Spinning Reserve	A06
<input type="checkbox"/> Voltage Support	A07
<input type="checkbox"/> Transmission Support	A08
<input checked="" type="checkbox"/> Transmission Congestion Relief	A09
<input checked="" type="checkbox"/> Service Reliability (Utility Backup)	A14
<input checked="" type="checkbox"/> Power Quality (Utility)	A16
<input type="checkbox"/> Wind Energy Time Shift (Arbitrage)	A18
<input checked="" type="checkbox"/> Solar Energy Time Shift (Arbitrage)	A19
<input type="checkbox"/> Renewable Capacity Firming	A20
<input type="checkbox"/> Wind Energy Smoothing	A21
<input type="checkbox"/> Solar Energy Smoothing	A22
<input checked="" type="checkbox"/> Retail TOU Energy Charges	A12
<input checked="" type="checkbox"/> Retail Demand Charges	A13
<input checked="" type="checkbox"/> Service Reliability (Customer)	A15
<input checked="" type="checkbox"/> Power Quality (Customer)	A17
<input checked="" type="checkbox"/> Black Start	A23



- The total value of combined applications are “estimated”
- PNNL is supporting a study to improve the estimated values by:
 - Substantiating estimates by using real data for each case
 - Enhancing the algorithm for calculating the combined values or “bundling”

Bundling Multiple Storage Applications

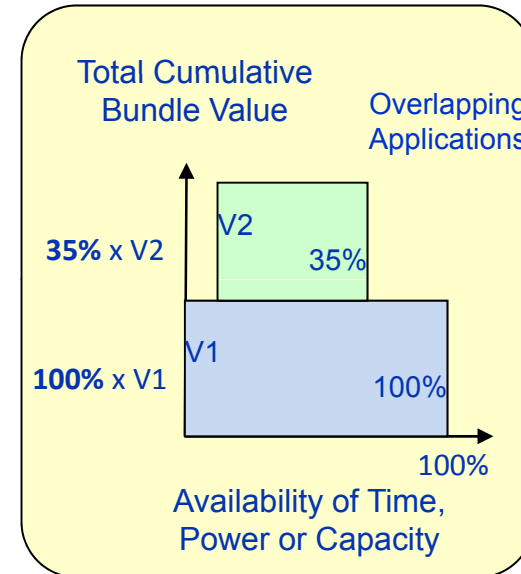
Low-Value Bundling



Stacked Applications

- **Dedicated** Storage Portions (capacity)
- Total Value = 45% V1 + 55% V2

High-Value Bundling



Overlapping Applications

- **Shared** Storage Portions (capacity)
- Total Value = 100% V1 + 35% V2

Total Value of Bundled Applications

The total value of bundled applications is the sum of the “utilized” or realizable values of each application

Total Value = 100% x Value 1	First (top Priority) application
+ UF ₂ x Value 2	second application
+ UF ₃ x Value 3	third application
+ UF ₄ x Value 4	fourth application
+ ...	

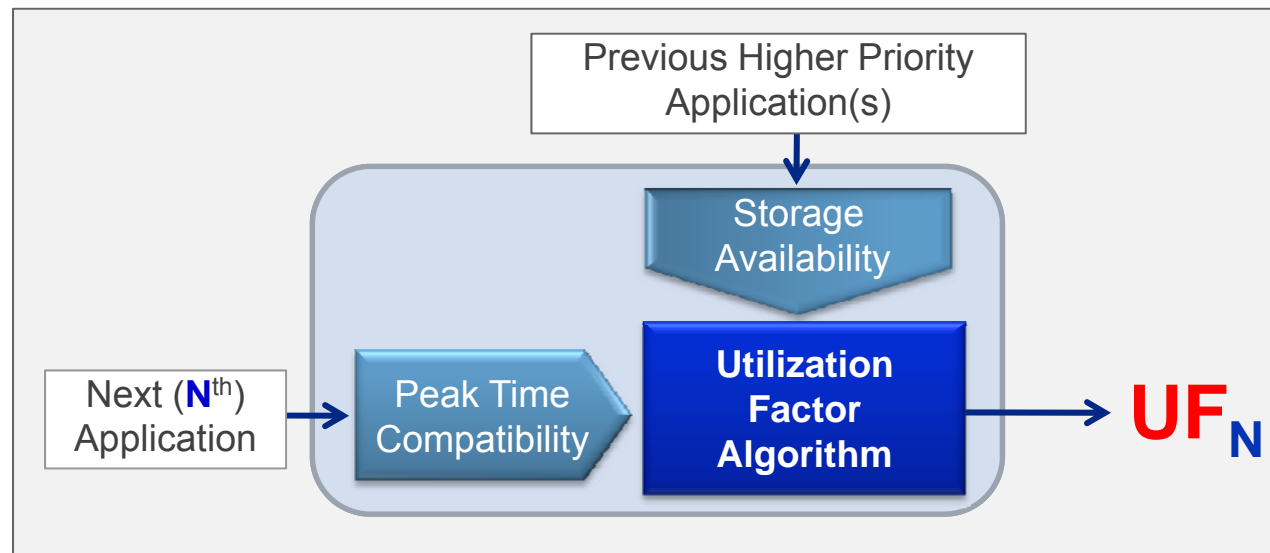
UF = Utilization Factor = portion of each application value that can be realized in the bundle of applications

Calculating Utilization Factors

DNV KEMA developed a process to quantify utilization factors (UF) for bundled applications.

$$\text{Combined Benefit} = \text{Bundle Benefit} + \text{UF} \times \text{Benefit of Next Application}$$

$$\text{UF} = \frac{\text{Value of a storage application in a bundle}}{\text{Value of the application by itself (no sharing of storage capacity)}}$$



Substantiated Utilization Factors (UF)

Following are four Bundling cases for which utilization factors have been calculated using real data from utility (loading), PJM (regulation) and NREL (PV output)

	Range
T&D deferral (V1) + Area Regulation (V2) =	V1+ (85% - 98%) V2
Retail Time of Use + Area Regulation =	V1+ (70% - 72%) V2
Solar Firming + Area Regulation =	V1+ (50% - 60%) V2
Solar Energy Time Shift + Area Regulation =	V1+ (35% - 55%) V2

Contents

1	Examples of DNV KEMA Tools
2	Review of ES-Select
3	Review of Distribution Valuation Model
4	Review of DNV KERMIT Model
5	Example of Applying to Use Case

Challenges at Distribution Level that Storage can address

Issues	Problems	Storage Solutions
Distributed Renewables	<ul style="list-style-type: none"> • Voltage fluctuations • Harmonics • Non-coincident production • Backfeed • Production variability • Loss of equipment life (due to above) 	<ul style="list-style-type: none"> • Volt / Var injection • Volt / Var injection • Energy time shifting • Energy time shifting • Firming • Improve system control (using above methods)
Asset Management	<ul style="list-style-type: none"> • Upgrade or capacity needed • Slow equipment deployment / approval • Uncertainty in amount of investment needed • Low asset utilization 	<ul style="list-style-type: none"> • Temporary capacity • Modular / transportable • Cheaper, smaller increments of re-usable capacity • Peak load shifting
Power Outages	<ul style="list-style-type: none"> • Lost revenue • Contract / regulatory penalties • Slow restoration process, e.g., cold load pick-up • Customer Outage costs & inconvenience 	<ul style="list-style-type: none"> • Utility service during Outage • Utility service during Outage • Facilitate restoration via Load Control • Service during Outages, quick to bring on-line
Electric Vehicle Integration	<ul style="list-style-type: none"> • Equipment loss of life, e.g., transf. cool-down • Equipment overloading & resulting Impacts 	<ul style="list-style-type: none"> • Relieves equipment loading • Increased capacity

Energy Storage Options / Locations / Formats

Energy Storage Types & Cost

- Lead Acid
- Flow Batteries
- Li-ion group
- NaS
- NaNiCl
- ...

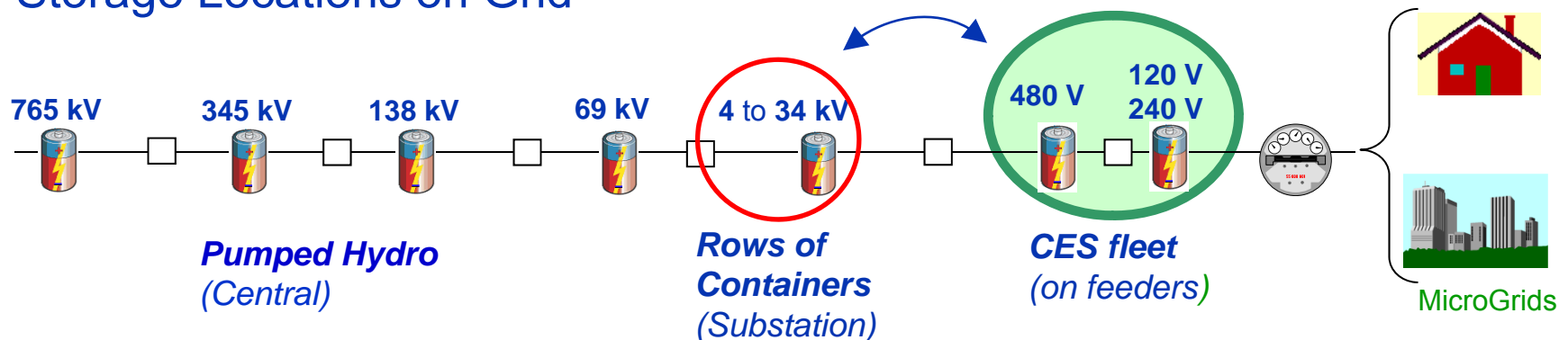
Solution Providers

- GE
- ABB
- S&C Electric
- Demand Energy
- ...

Plug-n-Play Packages

- CES
- Shipping Containers
- Mobile Trailers
- ...

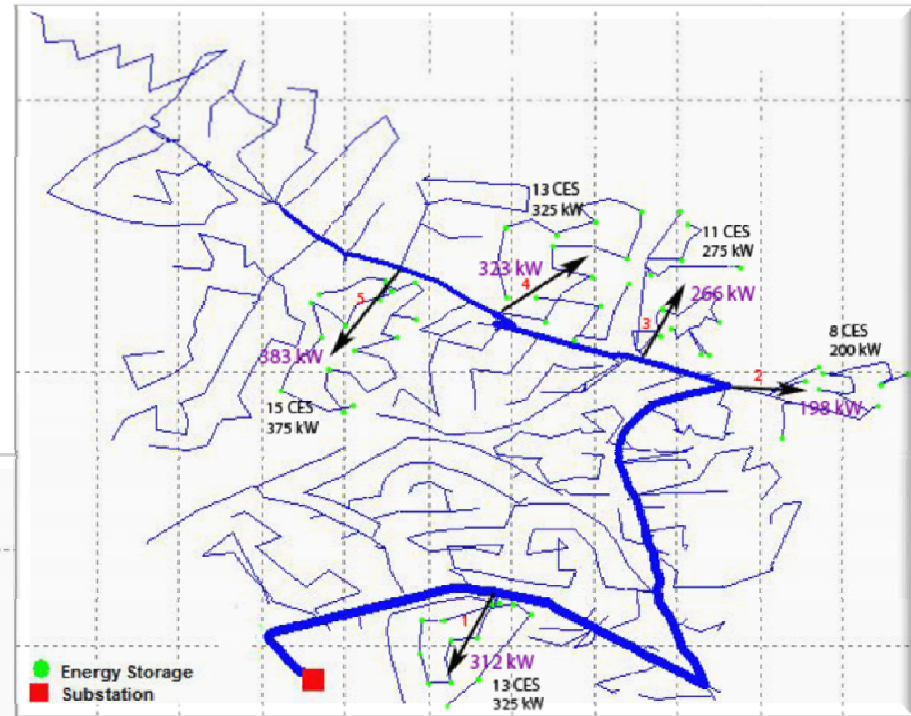
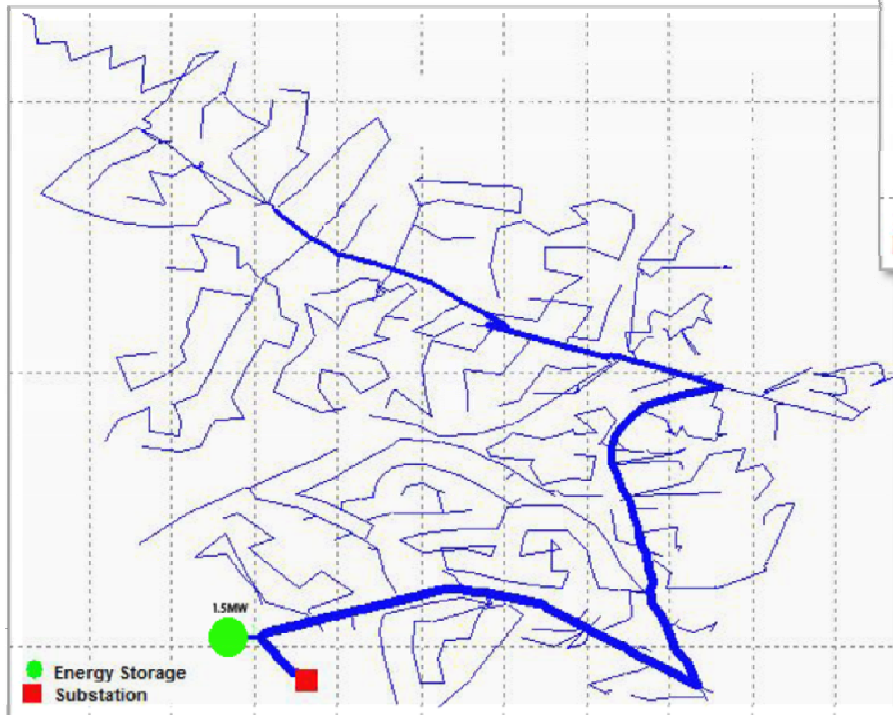
Storage Locations on Grid



Distributed Storage: Multiple versus a Single Unit

Substation versus edge of Grid

- Difference in performance
- Difference in benefits
- Difference in costs



Site	Peak Demand (kW)	Peak Demand (kVA)	# of Devices	Capacity (kW)
1	312	386	13	325
2	198	244	8	200
3	266	320	11	275
4	323	399	13	325
5	383	474	15	375

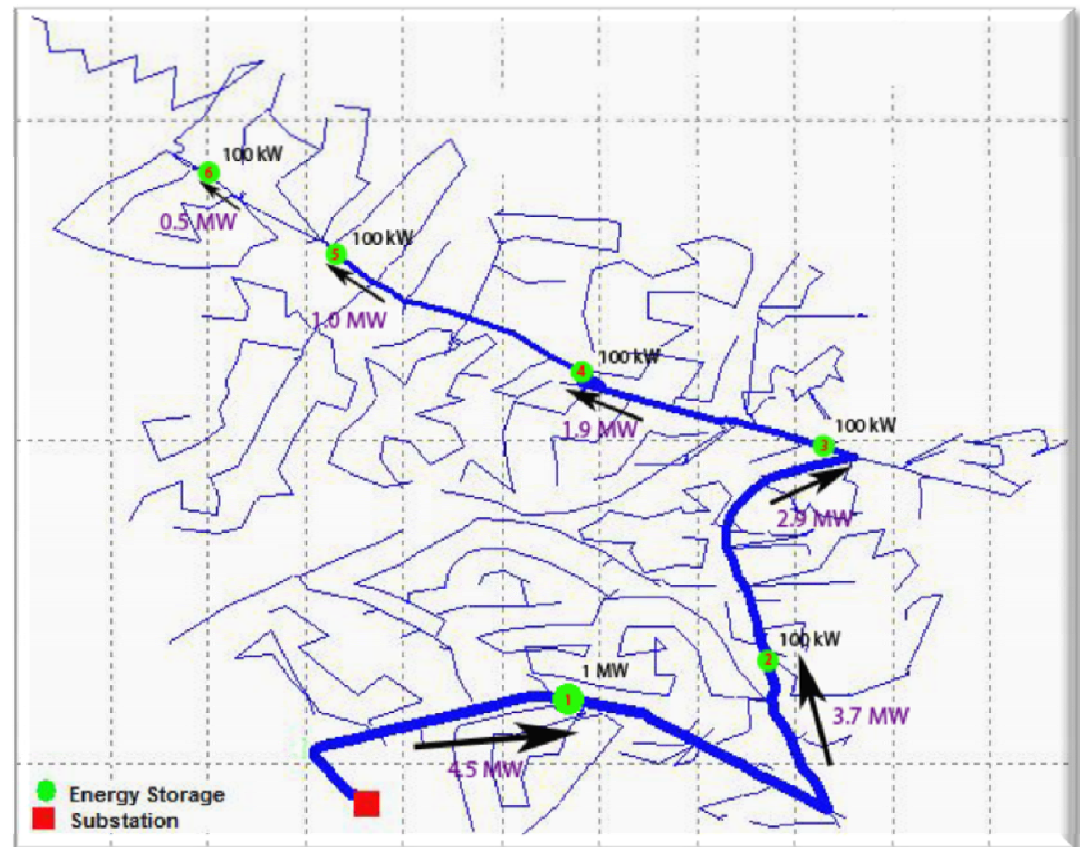
Assessing Storage Locations

Meeting Circuit Needs

- Storage solution tailored to circuit
- Evaluates multiple options
- Allows for identification of best value options

Site	Peak Demand (kW)	Peak Demand (kVA)
1	4,555	5,079
2	3,716	3,716
3	2,876	3,031
4	1,853	1,868
5	992	1,231
6	453	576

Example shows different storage sizes as a possible solution



Bundling & Controls

- Bundling applications allows you to achieve the maximum benefit for an investment
- Controls are key to efficient bundling
 - Does the battery have enough energy to serve an application when its needed?
 - Are applications compatible, and if not, which application has priority?
 - Does adding an application require additional capacity/energy and if so, is it cost effective for the incremental investment needed?
- Yet, controls must be robust and cost-effective to implement
 - Can the current communications infrastructure support the control scheme and if not, is the incremental investment worth it?
 - Are the controls simple enough to execute over all system conditions, but sophisticated enough to maximize value?
- DNV KEMA's analysis is flexible with regarding control schemes
 - The modeling analysis can incorporate multiple types of controls
 - The team is currently analyzing rule-based approaches and comparing these to 'theoretical', optimal schemes to gauge value

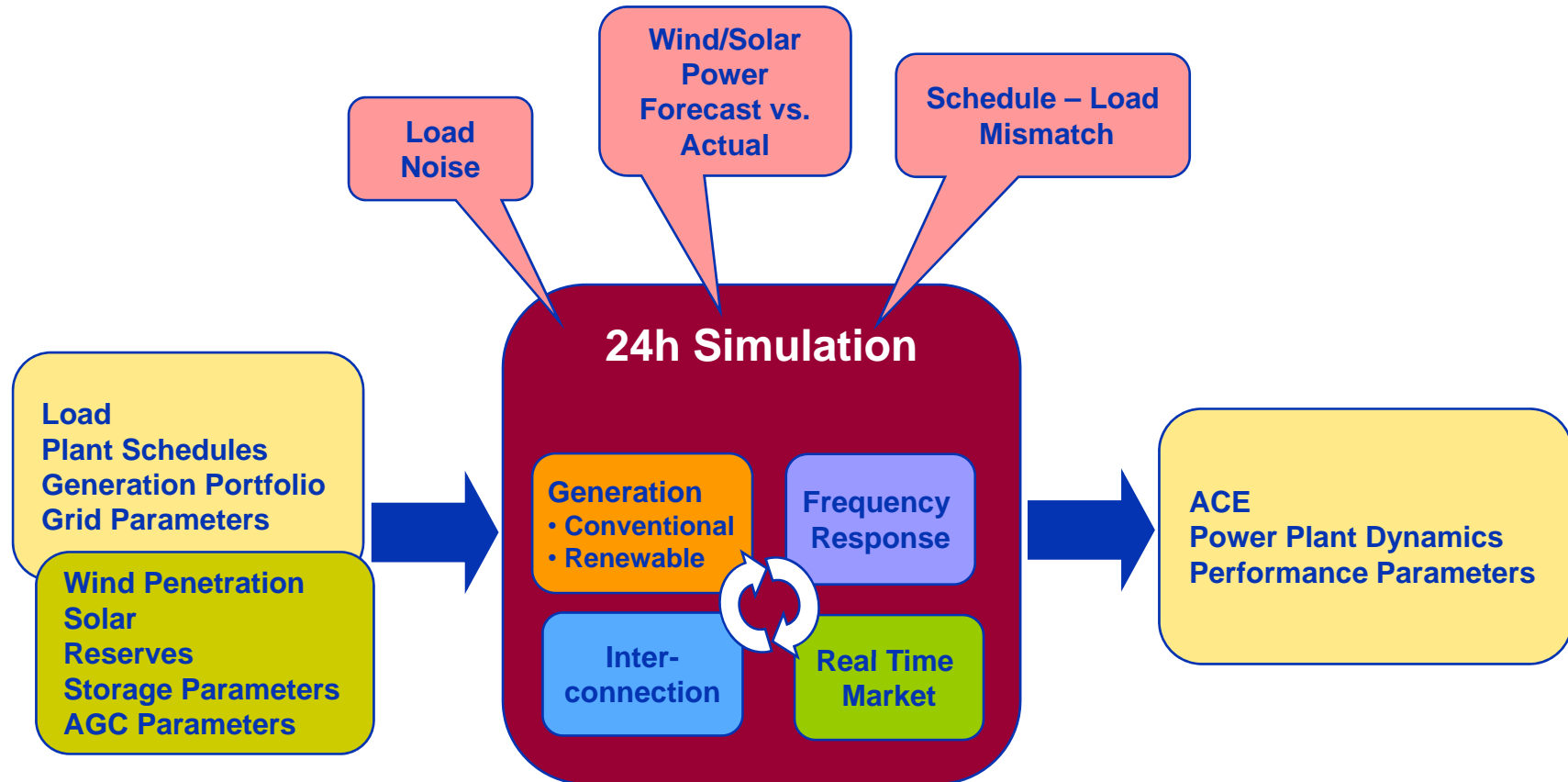
Contents

1	Examples of DNV KEMA Tools
2	Review of ES-Select
3	Review of Distribution Valuation Model
4	Review of DNV KERMIT Model
5	Example of Applying to Use Case

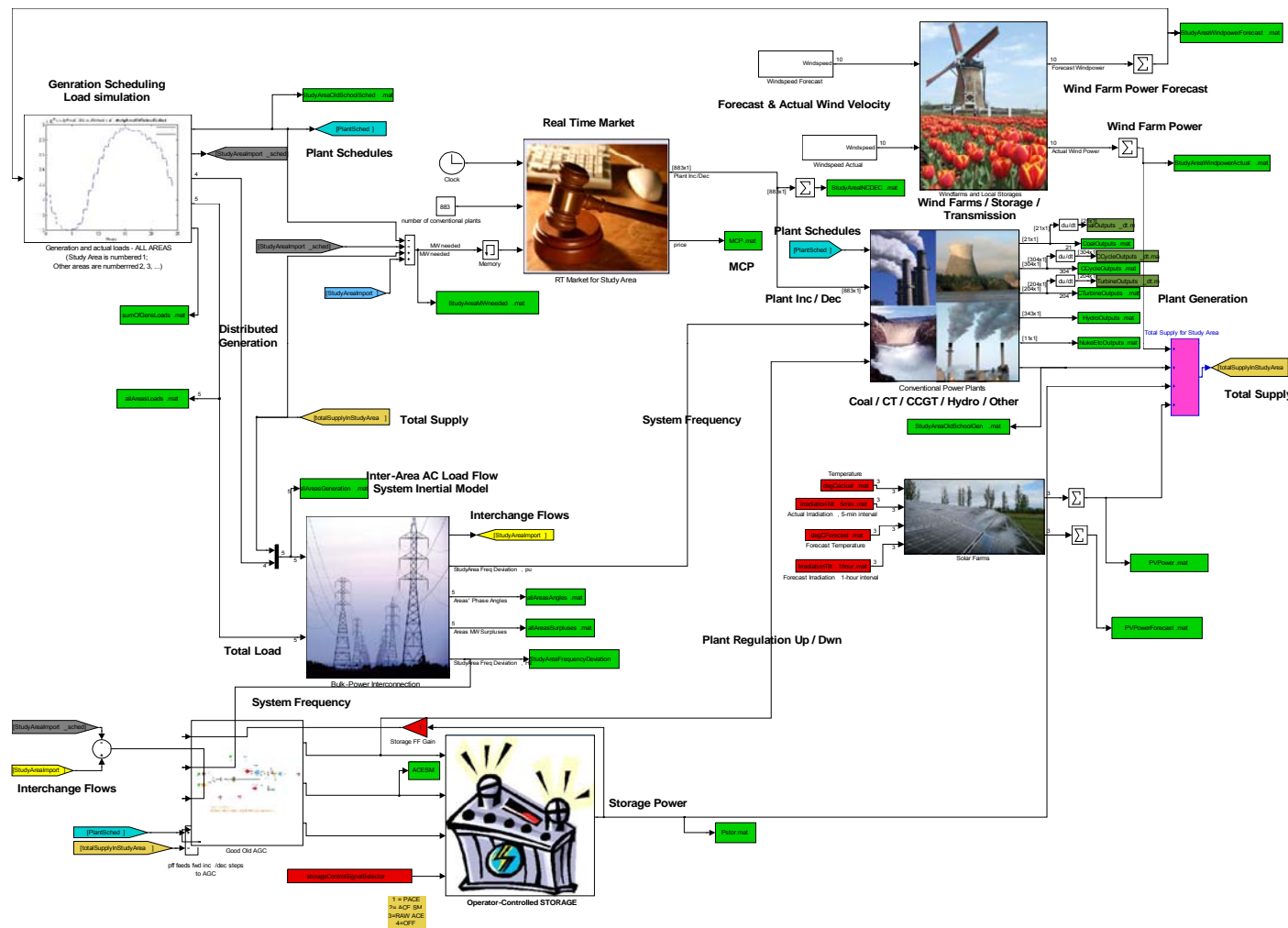
KEMA Renewable Energy Integration and Modeling Tool

- Developed by KEMA in Europe and the US
- Simulates Real Time Power System Dynamics
- Quantifies Impact of Variable Power Sources on System Operation
- Capabilities:
 - Effect on system dynamic when adding wind and solar to the generation mix
 - Assess opportunities for storage in regulation
 - Compare operation control strategies
 - Investigate integrated approach for wind, solar and storage

The Simulation Concept



Graphical User Interface



Simulink GUI
running MATLAB
code

New model is
scalable and fast

Typical
simulation span:
midnight to
midnight

Features of our Simulation Model

- Time Varying Generation and Loads
- Balancing Market for Electricity
- Dynamics of Conventional Power Plants
- Automatic Generation Control
- Bulk Power Interconnection Dynamics
- Wind Farms
- Photo Voltaic
- Storage (Operator Controlled and Local)
- Emissions (CO₂, NO_x)

Areas of focus for Tool

- Continue to Explore “Fast Regulation Services” Possibilities
- Protocols for Renewable Operation
 - Example: partial shut-down in anticipation of fall-off
 - Matching wind farm peak capacity plus storage to transmission limits
- Evaluate Impact of Changes in Balancing Market
 - Different look-ahead schemes
 - More Frequent Operation
- Explore Demand Side Impacts
- Model Actual Plant Regulation Activity
- Model Emissions Impact of Decreased Plant Regulation

Contents

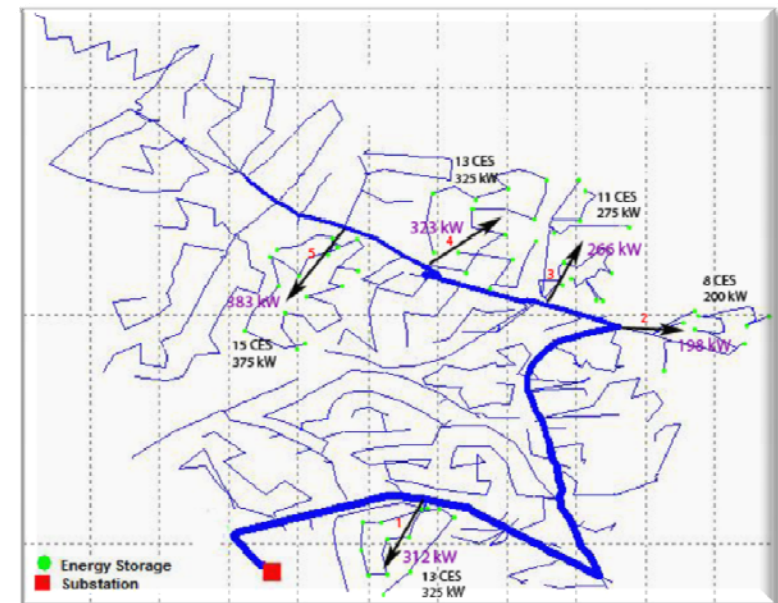
1	Examples of DNV KEMA Tools
2	Review of ES-Select
3	Review of Distribution Valuation Model
4	Review of DNV KERMIT Model
5	Example of Applying to Use Case

Use Example of Use Case - Distributed Storage

- How will tools be applied to the specific examples
 - In the suite of DNV KEMA Tools, will utilize ES-Select and draw upon Distribution Valuation model as required
- Why ES-Select
 - Incorporates cost and comparison of all potential storage technologies
 - Capable of bundling additional applications into the analysis in order to maximize the benefits that are used in the cost effectiveness evaluation
- Example of Use Case – Deferral of Distribution Upgrades
 - Primary Application – Deferral
 - Secondary applications
 - Reliability
 - Peak Shaving
 - Volt-Var Control

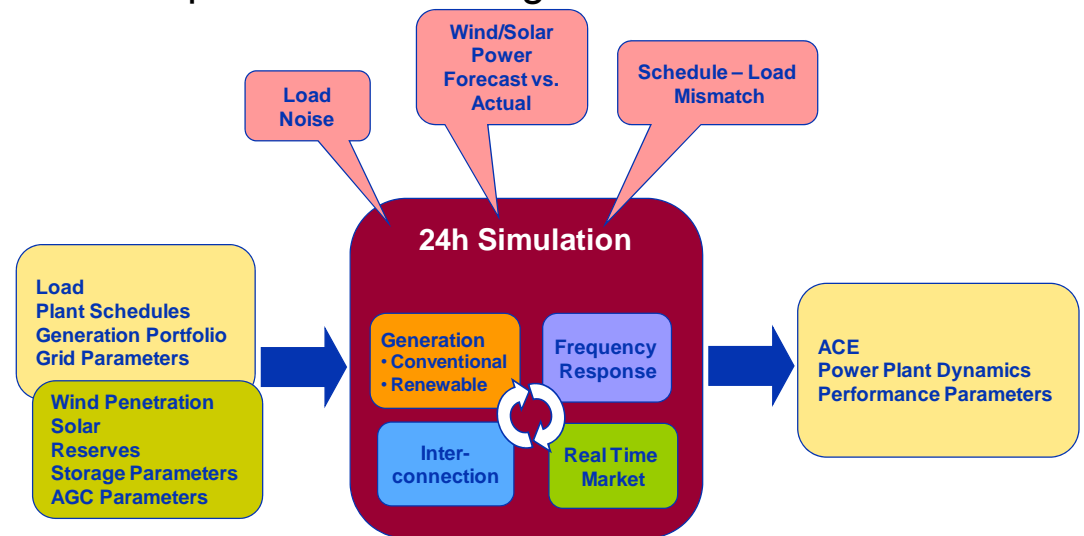
Use Example of Use Case - Distributed Storage

- Use Case Development – Model to Cost effectiveness
 - Benefits and Cost will be defined through ES-Select
 - Comparison of alternative approaches will flow through financial modeling of the applications
- Additional areas of analysis
 - Utilization of Distribution Valuation model
 - Defines distributed storage
 - Substation vs. Edge of the Grid



Use Example of Use Case – Ancillary Services

- As applications transition to Wholesale – Bulk Applications, DNV KEMA will Utilize additional tools
- Utilization of KERMIT Model
 - In the suite of DNV KEMA Tools, will utilize KERMIT Model to provide analysis of the primary application
 - Model is already calibrated for the CAISO system
 - Tap into ES-Select tools to examine the potential technologies that can be utilized in the analysis



Use Example of Use Case – Ancillary Services

- Bundling of applications with Ancillary Services?
 - In Use Case Analysis, where possible, potential bundling will be examined in the cost effectiveness approach

